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Desnijder et al.

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(54) **CROP PROCESSOR AND A MANUFACTURING PROCESS FOR A CROP PROCESSOR**

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See application file for complete search history.

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(57) **ABSTRACT**

A crop processor for cracking kernels in a forage harvester, the crop processor including: a housing having an inlet and an outlet; and a first and a second comminuting roll mounted inside the housing, the comminuting rolls being arranged in parallel to define an opening between the rolls, the comminuting rolls being configured to rotate, during use, in opposing rotation directions to transport a flow of harvested crop, received from the inlet, through the opening towards the outlet, wherein the first comminuting roll is configured to
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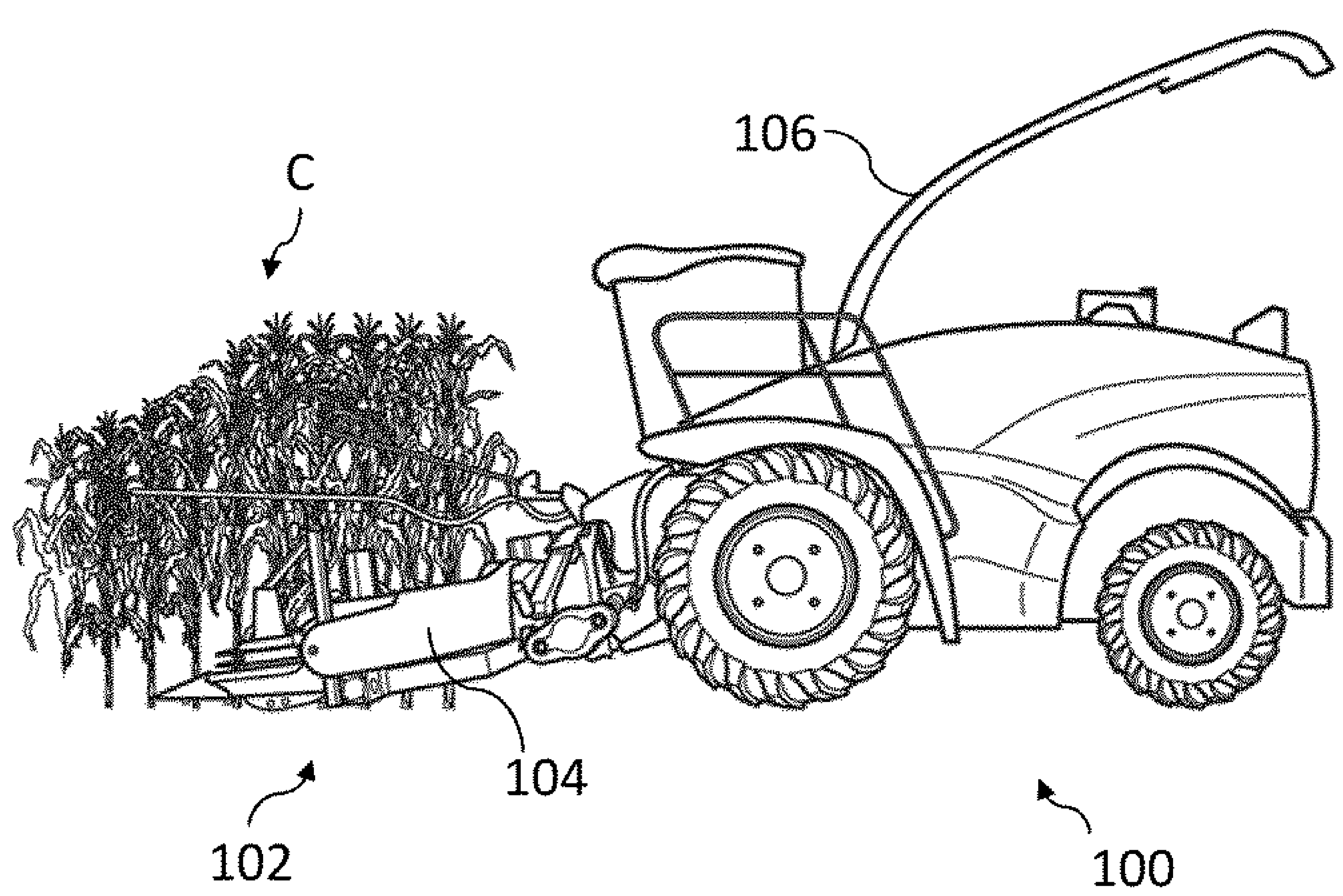

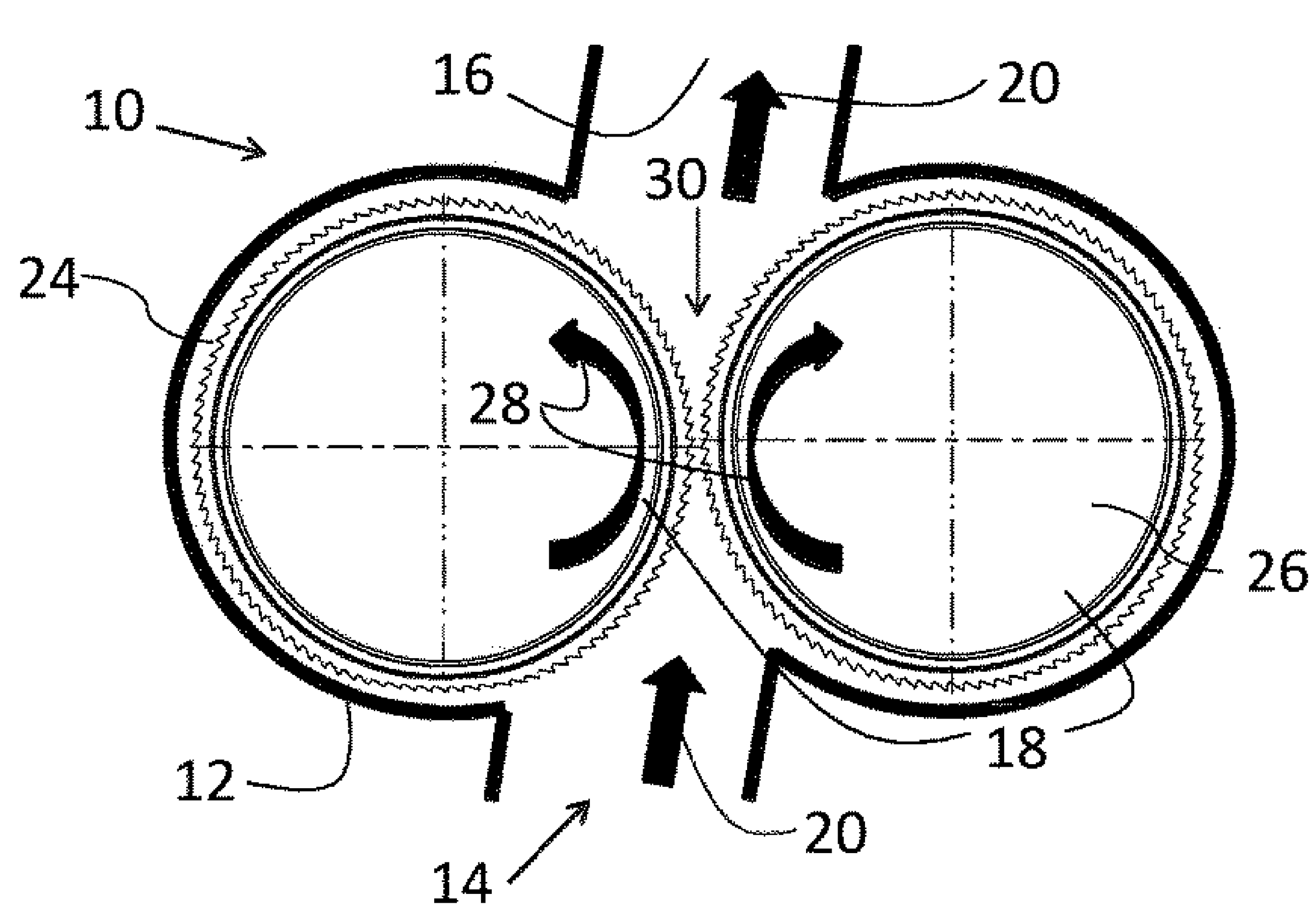

rotate at a greater speed than the second comminuting roll; wherein the first and second comminuting rolls each include a plurality of teeth arranged on a circumferential surface of the comminuting roll, each of the plurality of teeth includes a leading edge which faces in the rotation direction of that comminuting roll.

14 Claims, 7 Drawing Sheets

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B02C 4/06	(2006.01)
B02C 4/30	(2006.01)

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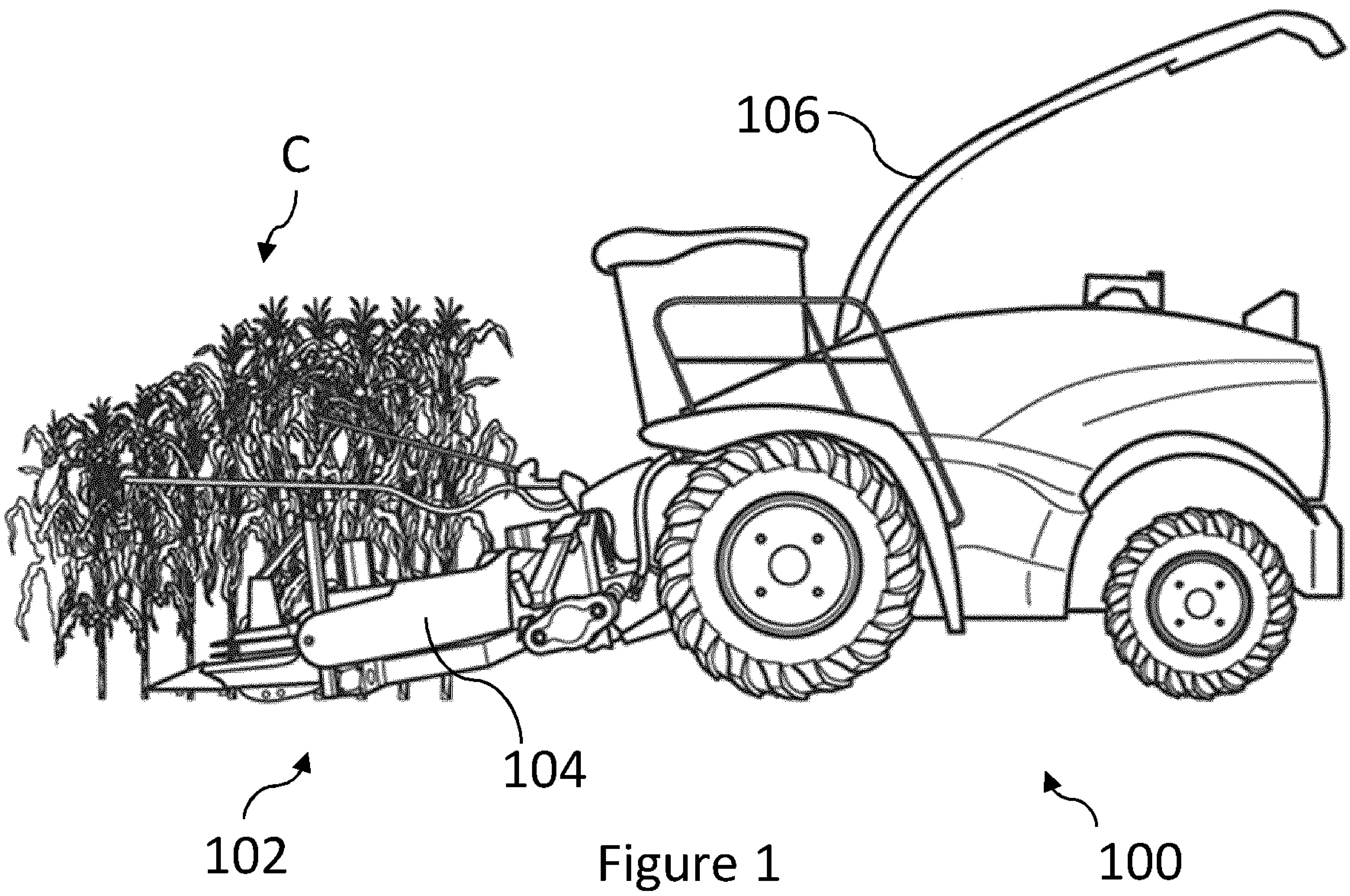

Figure 1

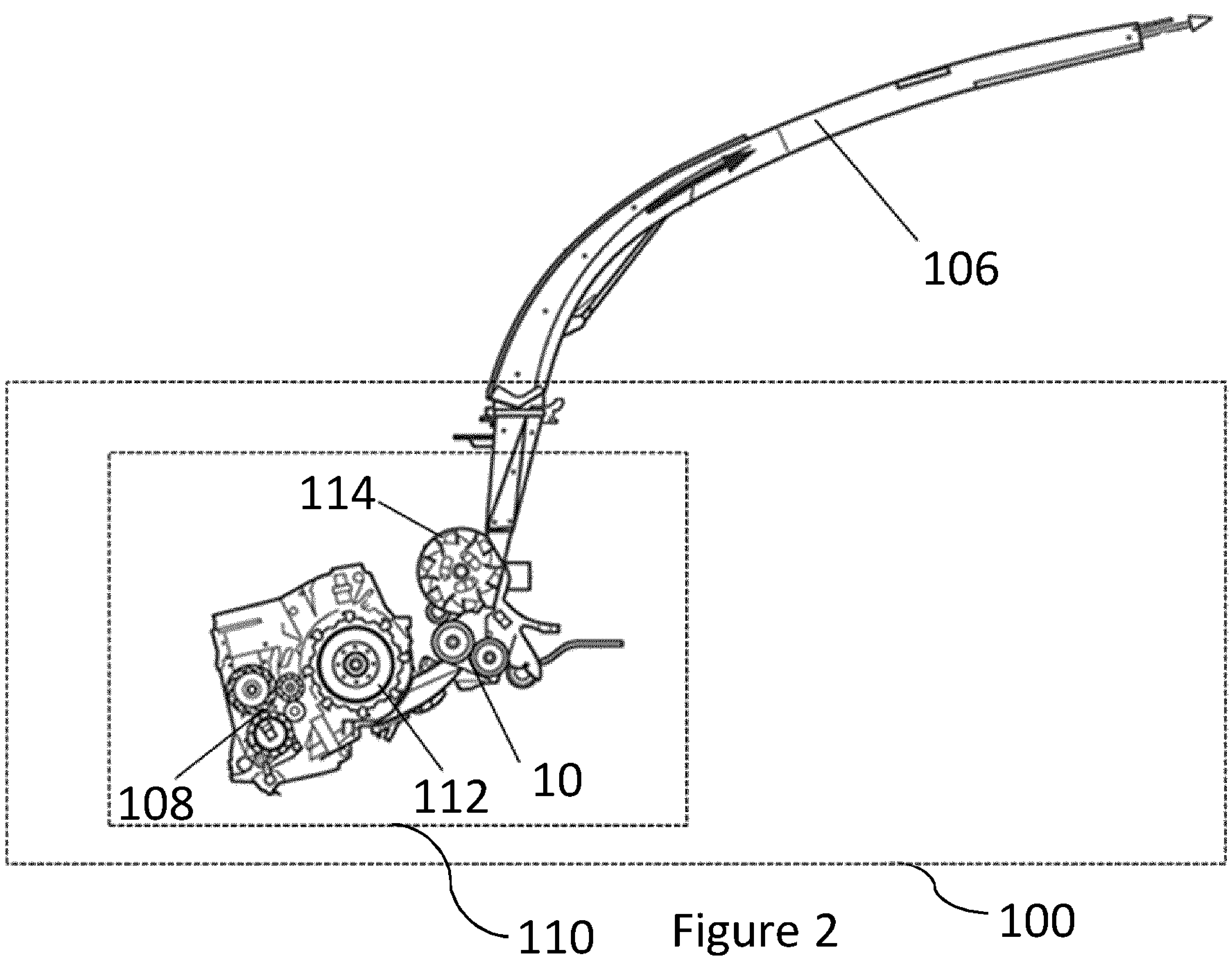

Figure 2

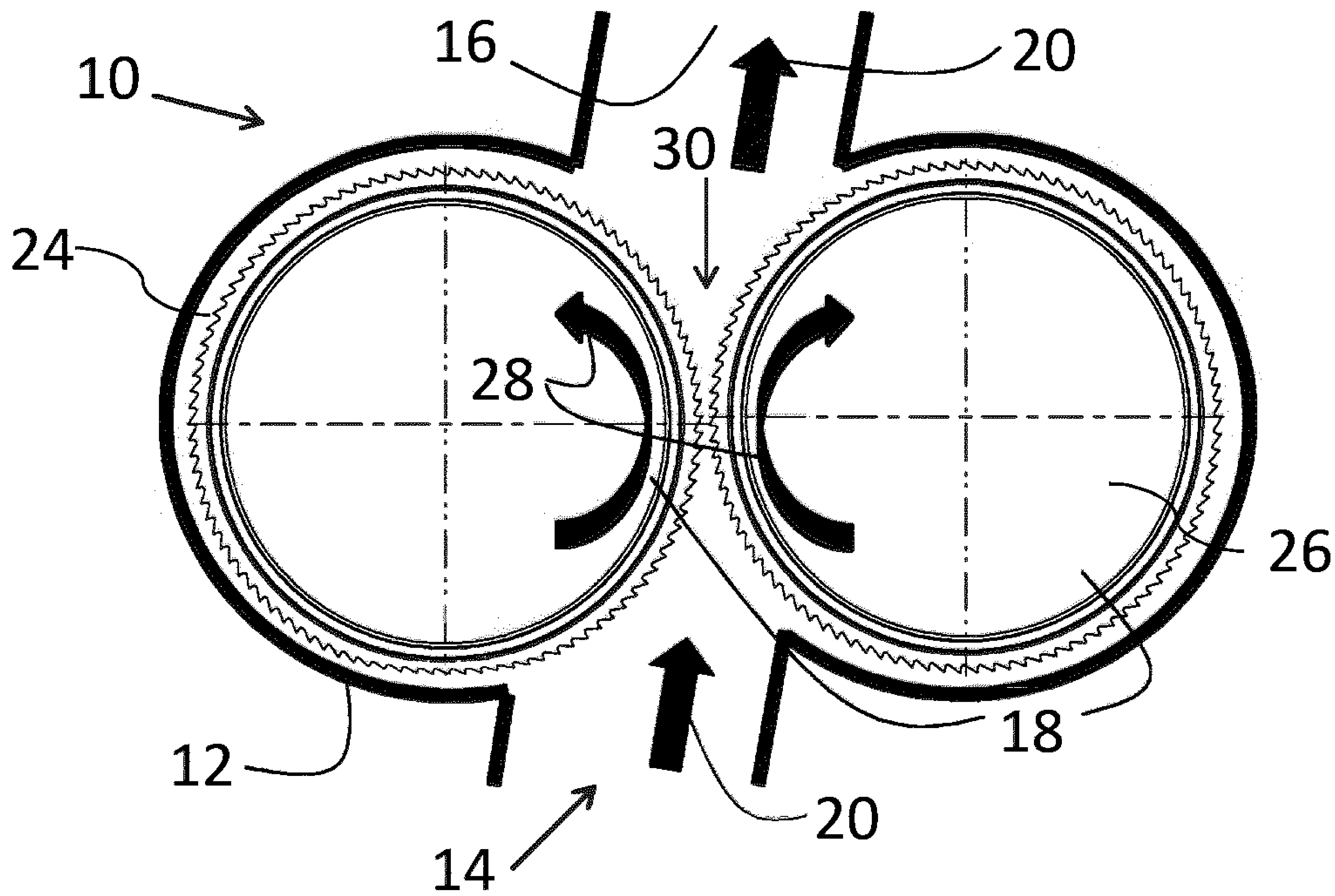

Figure 3

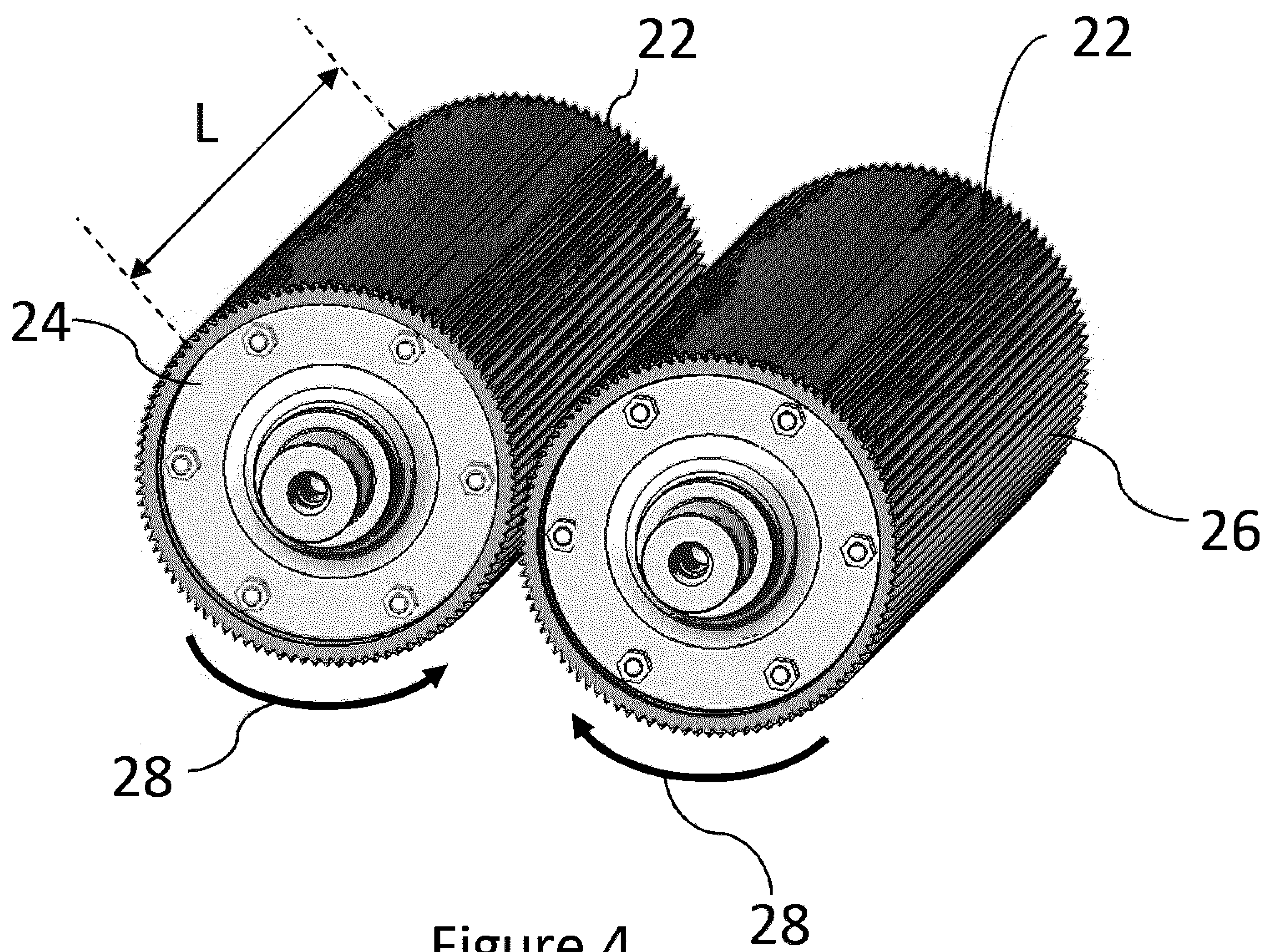

Figure 4

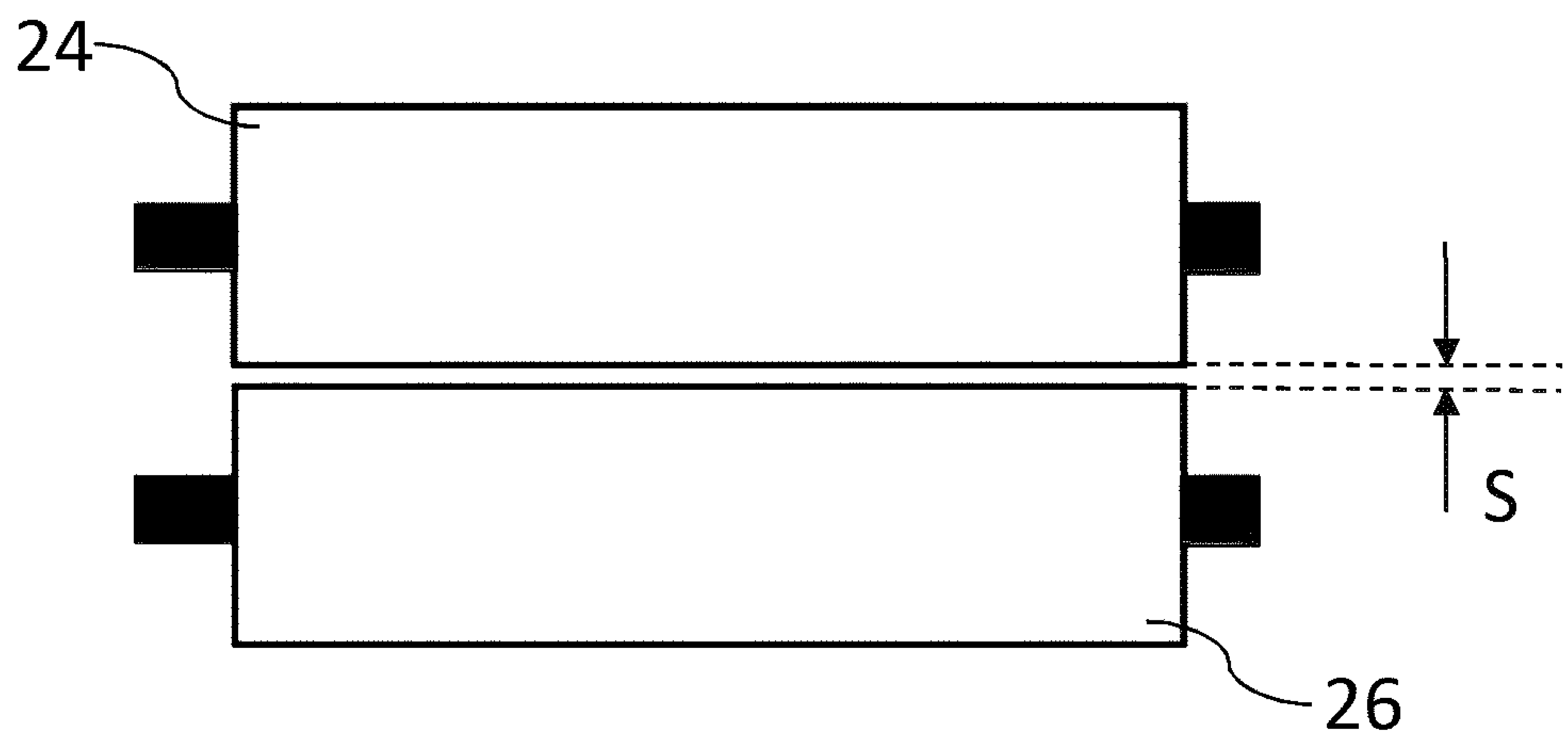

Figure 5

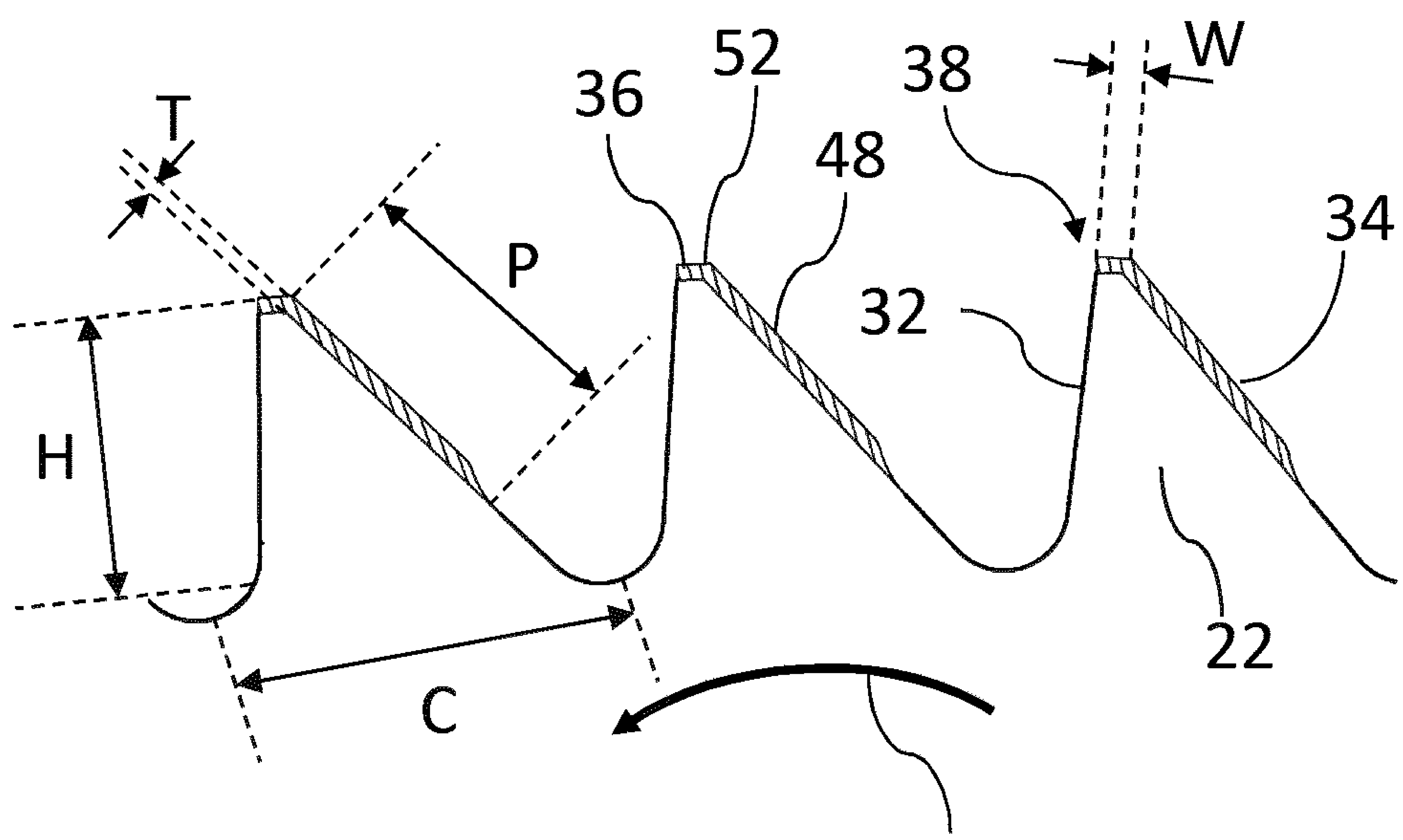

Figure 6

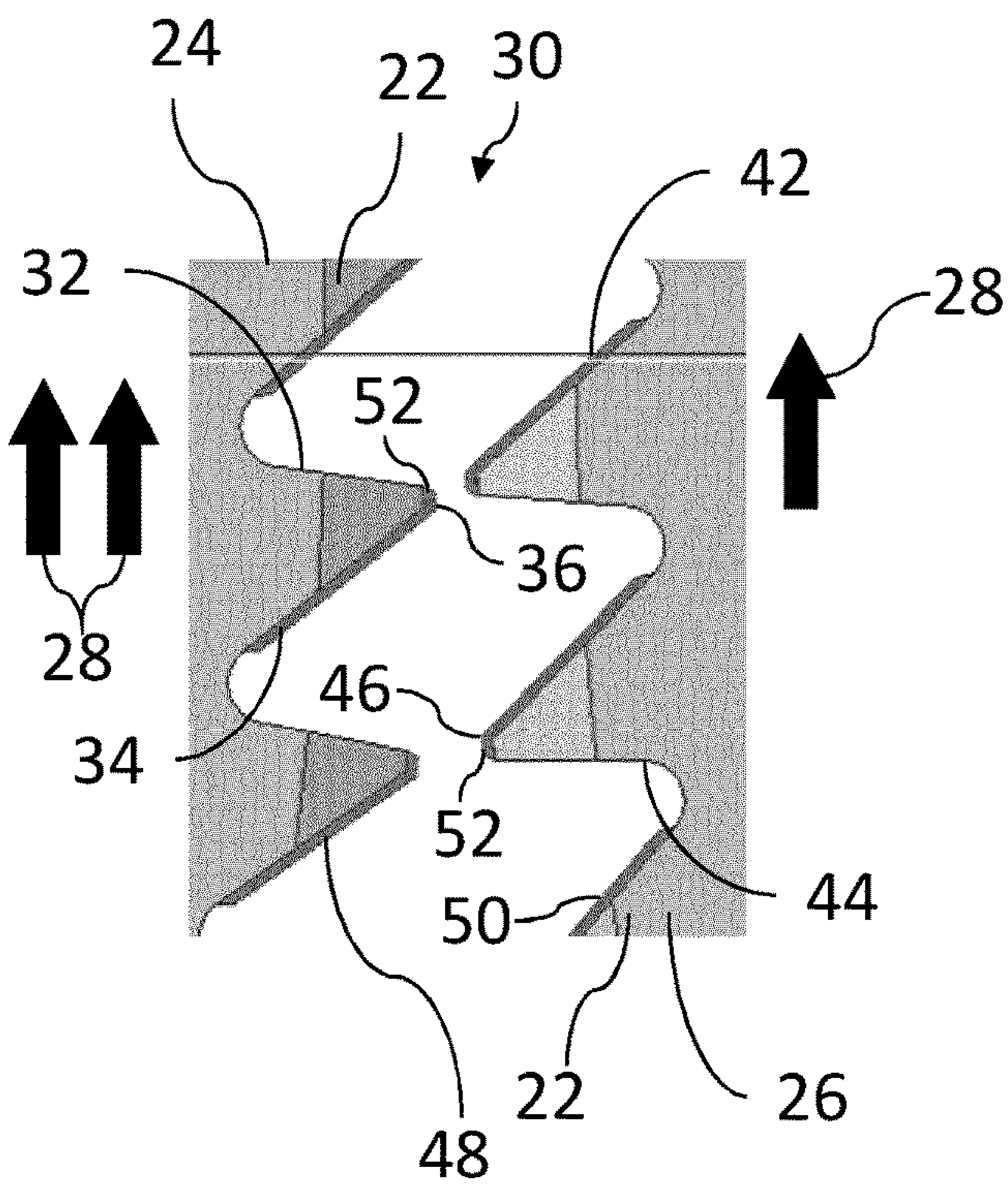

Figure 7a

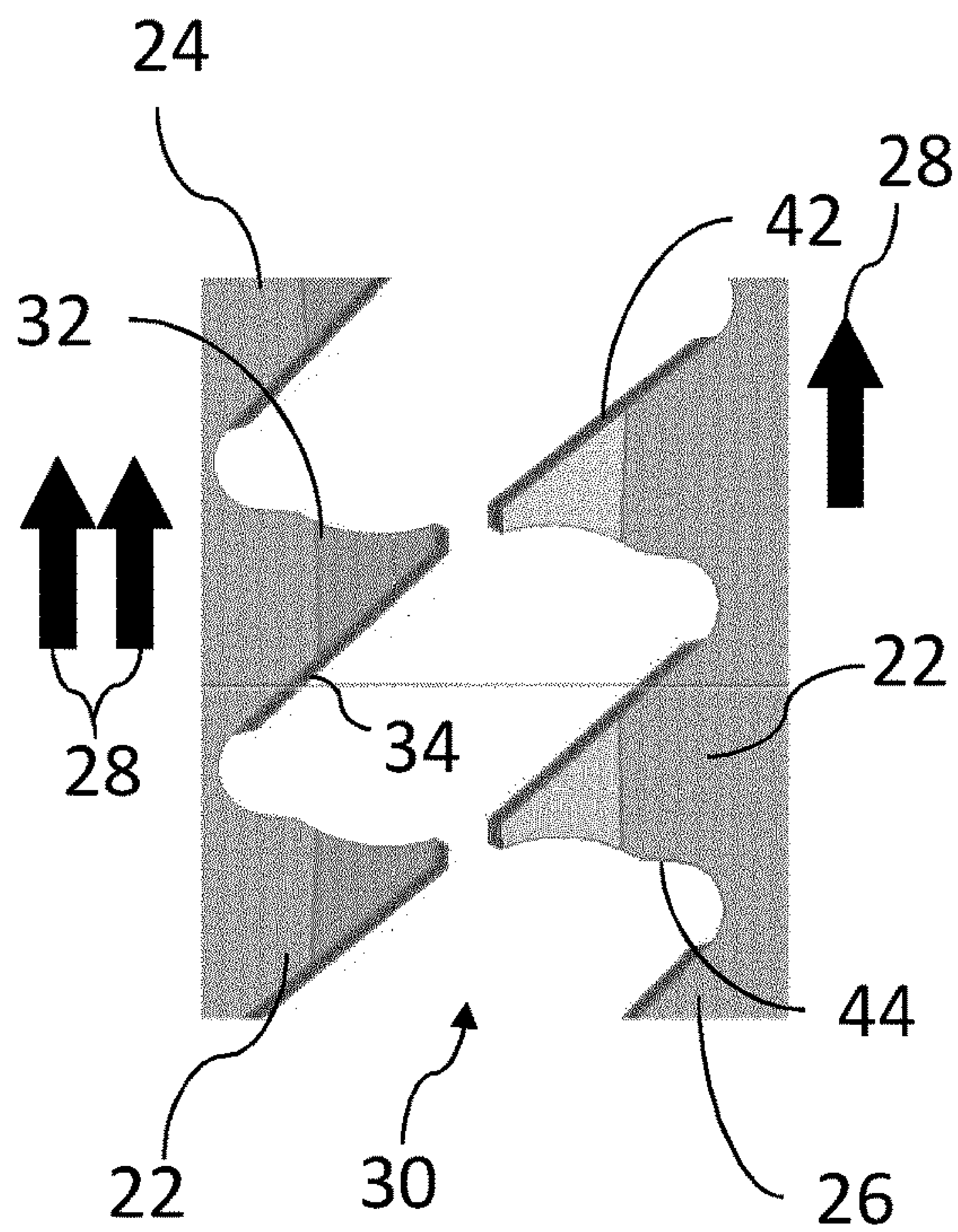

Figure 7b

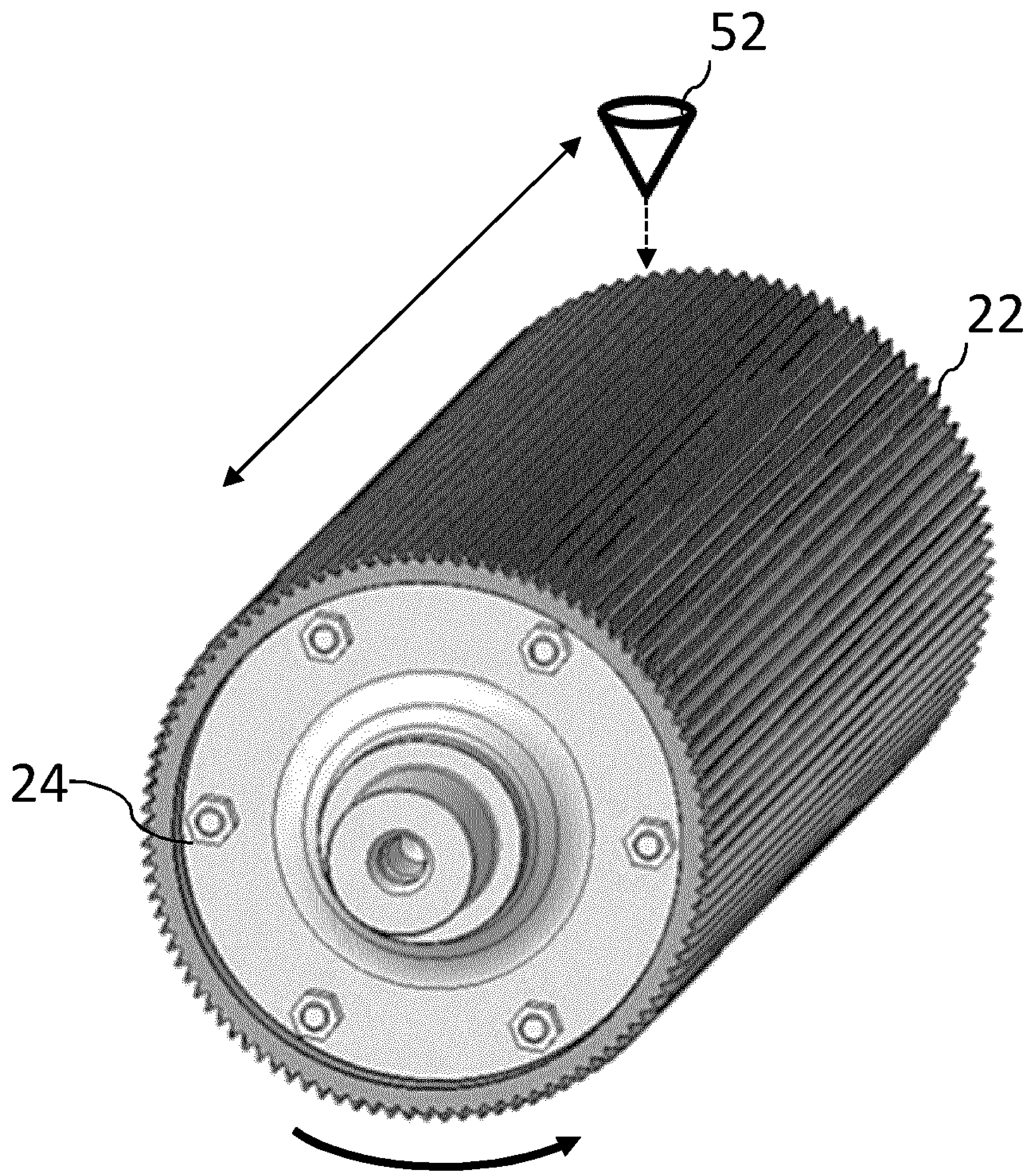

Figure 8

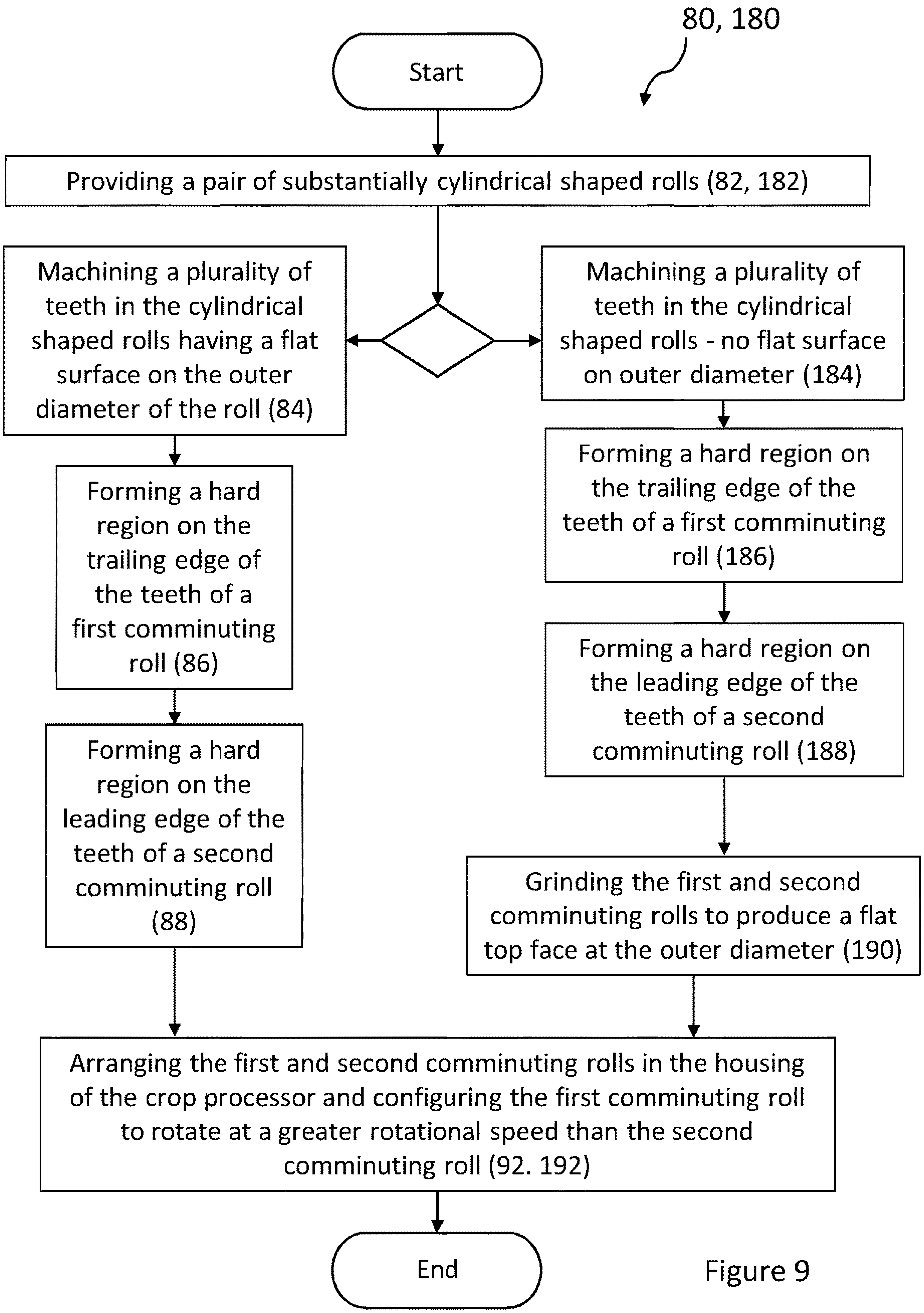
80, 180
Start
Providing a pair of substantially cylindrical shaped rolls (82, 182)
Machining a plurality of teeth in the cylindrical shaped rolls having a flat surface on the outer diameter of the roll (84)
Machining a plurality of teeth in the cylindrical shaped rolls - no flat surface on outer diameter (184)
Forming a hard region on the trailing edge of the teeth of a first comminuting roll (86)
Forming a hard region on the trailing edge of the teeth of a first comminuting roll (186)
Forming a hard region on the leading edge of the teeth of a second comminuting roll (88)
Forming a hard region on the leading edge of the teeth of a second comminuting roll (188)
Grinding the first and second comminuting rolls to produce a flat top face at the outer diameter (190)
Arranging the first and second comminuting rolls in the housing of the crop processor and configuring the first comminuting roll to rotate at a greater rotational speed than the second comminuting roll (92. 192)
End

Figure 9

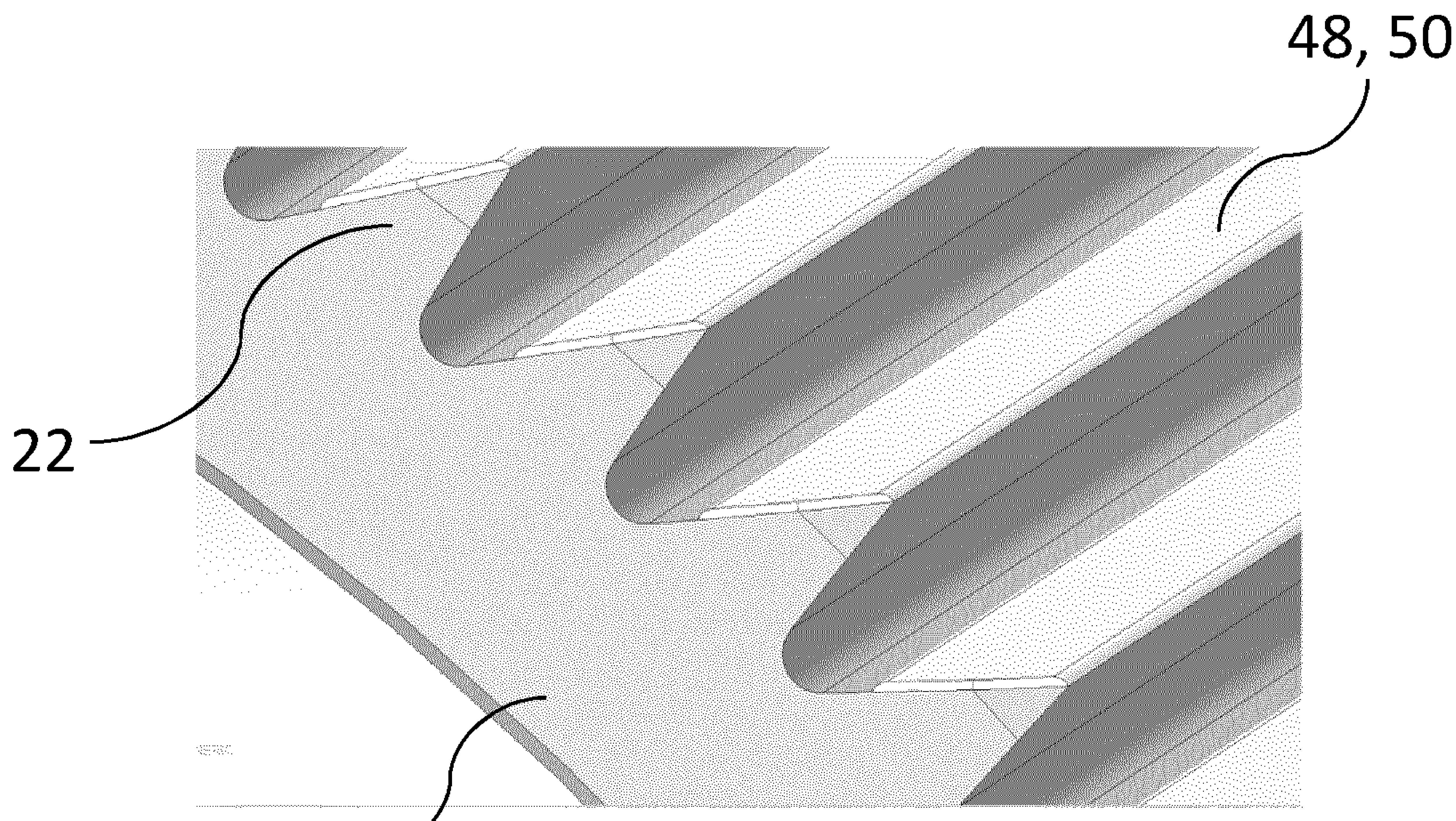

Figure 10

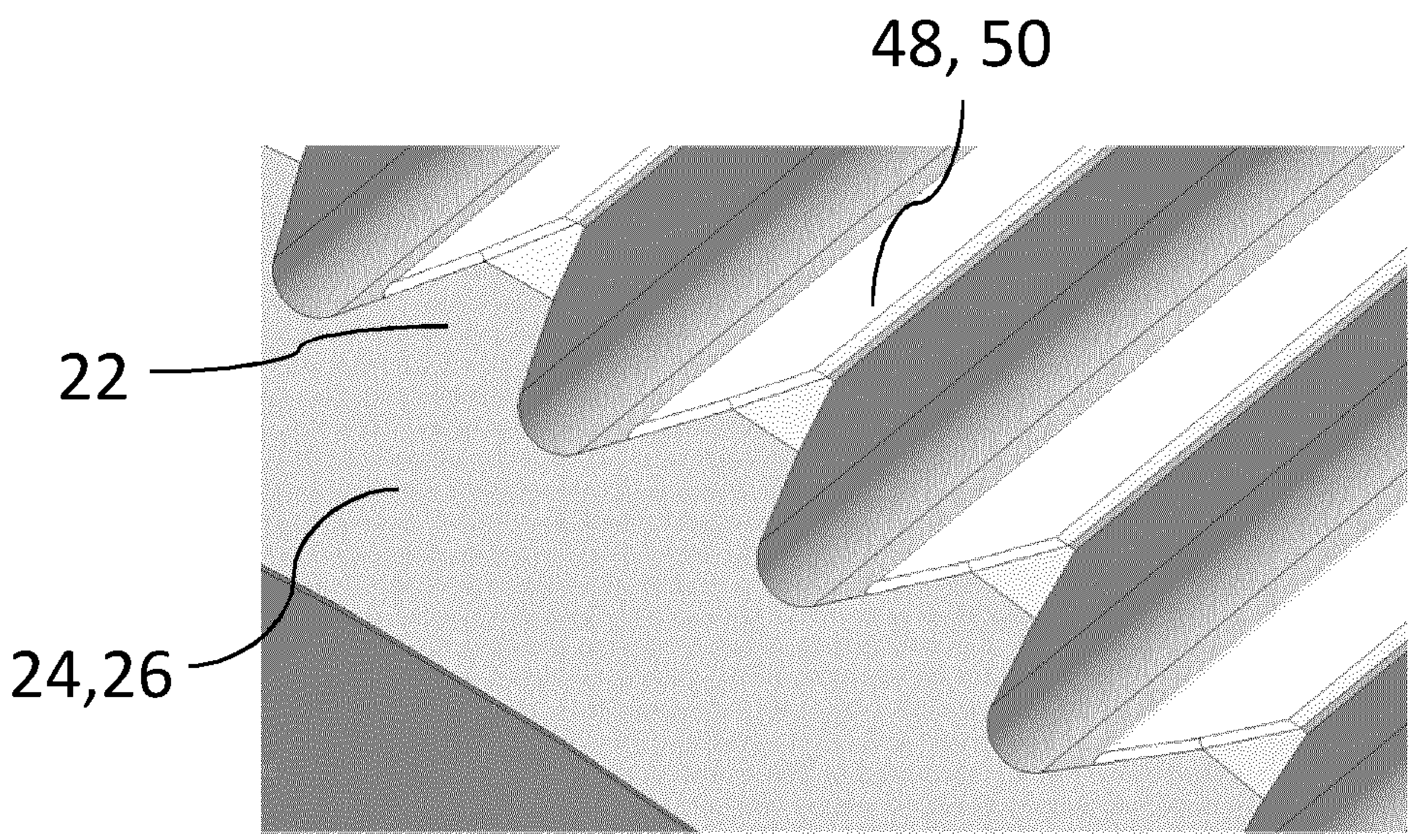

Figure 11

CROP PROCESSOR AND A MANUFACTURING PROCESS FOR A CROP PROCESSOR

TECHNICAL FIELD

The present invention relates to the field of forage harvesters, and more specifically to crop processors for cracking crop kernels in such harvesters. The invention also relates a method of manufacturing a crop processor for a forage harvester.

BACKGROUND

Forage harvesters are used to harvest crop from a field and to then comminute the harvested crop before expelling it through a spout and into a trailer traveling in close proximity of the forage harvester. Forage harvesters are often equipped with a crop processor that cracks—or pulverises—the kernels in the harvested crop. Typically, the crop processor includes a pair of crop comminuting rolls, each having a plurality of teeth on their circumference; the teeth having a height in radial direction and extending in axial direction of the rolls.

Both of the crop comminuting rolls are mounted in a housing which comprises an inlet and an outlet. The comminuting rolls are arranged such that there is a small opening between their outer peripheries. During use, the crop comminuting rolls are rotated in opposing circumferential directions (i.e. one roll is rotated in a clockwise direction and the other roll is rotated in a counter-clockwise direction) such that the harvested crop, which is fed to the rolls via the inlet, is passed through the small opening between the rolls, thereby cracking the kernels by means of the teeth. The flow of harvested crop is then expelled from the housing via the output.

The wear caused by the kernel cracking process, itself, can also result in the formation of irregular openings between the rolls, e.g. when the flow of material is not uniformly distributed along the length of the rolls. Wearing of the teeth can inhibit the crop processor's ability to crack crop kernels consistently. As a result, the comminuting rolls must be replaced at more regular intervals, thereby increasing the maintenance costs of the forage harvester.

To enable the teeth to withstand wear caused by the kernel cracking, it is known to configure the teeth of the comminuting rolls such that the leading and trailing edges of the teeth exhibit a uniform hardness. For example, the comminuting rolls are subjected to an induction hardening treatment which involves inducing an alternating magnetic field in the surface of the comminuting rolls to cause localised heating of the roll's peripheral surface to a temperature which is above the transformation range of the constituent alloy. The localised heating leads to hardening of the peripheral surface which results in an equal hardening effect on both the leading and trailing edges of the teeth.

To further increase the wear resistance of the comminuting rolls, the surface of the teeth can also be coated with a thin hard chrome layer, following the induction hardening treatment. Such chrome plating techniques typically require the use of hexavalent chromium which is a toxic substance, the use of which is increasingly restricted by government legislation.

A drawback of induction hardening process is that it tends to concentrate energy in a tip region of the teeth, causing localised melting of the tip region. The hardening process also causes deformation in the roll due to metallurgical

transitions in the material. A disadvantage of the chrome electro-plating process is that it causes indiscriminate hardening of both the leading and trailing edges of the teeth, which contributes to the irregular wearing of the comminuting rolls during operation of the crop processor. In particular, the uniform hardening causes a gradual, but irreversible blunting of the teeth of the comminuting rolls during operation of the crop processor.

It would be desirable to improve the resistance to wear of the comminuting rolls of a crop processor for a forage harvester.

SUMMARY OF INVENTION

According to a first aspect of the invention there is provided a crop processor for cracking kernels in a forage harvester, the crop processor comprising: a housing having an inlet and an outlet; and a first and a second comminuting roll mounted inside the housing, the comminuting rolls being arranged in parallel to define an opening between the rolls, the comminuting rolls being configured to rotate, during use, in opposing rotation directions to transport a flow of harvested crop, received from the inlet, through the opening towards the outlet, wherein the first comminuting roll is configured to rotate at a greater speed than the second comminuting roll; wherein the first and second comminuting rolls each comprise a plurality of teeth arranged on a circumferential surface of the comminuting roll, each of the plurality of teeth comprises a leading edge which faces in the rotation direction of that comminuting roll; wherein the leading edge of the teeth of the second comminuting roll comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

During operation of the crop processor, crop material is crushed between the leading edge of the faster moving first comminuting roll and the trailing edge of the slower moving second comminuting roll. Advantageously, the leading edge of the teeth of the first comminuting roll is worn relative to the trailing edge which leads to a sharpening of the teeth of the first comminuting roll by the crop material, which thereby prolongs the life of the crop processor.

The teeth of the first comminuting roll may comprise a trailing edge which faces away from the rotation direction of the first comminuting roll, the trailing edge comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

The hard region of the leading edge of the teeth of the second comminuting roll may have a greater hardness than a trailing edge of the teeth of the second comminuting roll arranged to face away from the rotation direction of the second comminuting roll. Similarly to the first comminuting roll, the trailing edge of the second comminuting roll will be caused to wear away quicker than the hard region of the leading edge, which will result in a sharpening of the teeth of the second comminuting roll during operation of the crop processor.

The hard region of the trailing edge of the teeth of the first comminuting roll may be configured with a hardness which is greater than the trailing edge of the teeth of the second comminuting roll. The hard region of the leading edge of the teeth of the second comminuting roll may be configured with a hardness which is greater than the leading edge of the teeth of the first comminuting roll.

The plurality of teeth of the first comminuting roll may comprise a substantially flat-top edge. The substantially flat-top edge may comprise a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

The plurality of teeth of the second comminuting roll may comprise a substantially flat-top edge. The substantially flat-top edge may comprise a hard region having a greater hardness than the trailing edge of the teeth of the second comminuting roll.

The hard region may comprise a wear resistant layer having been deposited by laser-cladding. The wear resistant layer may comprise tungsten carbide.

The plurality of teeth may comprise an air hardened surface region. The plurality of teeth may be manufactured from steel, or any suitable material which has sufficient hardenability to enable air hardening of the teeth surfaces.

At least one edge of the teeth may comprise a laser hardened surface region. The laser hardened surface region may be formed on an edge of the teeth which is not clad with wear resistant material.

The plurality of teeth may have an asymmetrical profile in an axial section of the comminuting roll. The axial section is defined as a cross section obtained by slicing through the comminuting roll, along a plane which intersects at a right angle to the longitudinal axis of the roll. The axial plane may otherwise be defined as the transverse section of the roll.

According to a second aspect of the invention, there is provided a forage harvester comprising a crop processor according to any of the preceding paragraphs.

According to third aspect of the invention, there is provide a method of manufacturing a crop processor for cracking kernels in a forage harvester, the method comprising: manufacturing a first and a second comminuting roll; and, assembling the comminuting rolls into a housing having an inlet and an outlet, the comminuting rolls being arranged in parallel to define an opening between the comminuting rolls, the comminuting rolls being configured to rotate, during use, in opposing directions to transport a flow of harvested crop, received from the inlet, through the opening towards the outlet, wherein the first comminuting roll is configured to rotate at a greater speed than the second comminuting roll; wherein manufacturing the crop comminuting rolls comprises: providing a pair of substantially cylindrical shaped rolls; machining a plurality of teeth in the substantially cylindrical shaped rolls, each of the plurality of teeth comprising a leading edge arranged, during use, to face in a rotation direction of the crop comminuting roll; and forming a hard region on the leading edge of the teeth of the second comminuting roll, the hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

The method may comprise forming a hard region on a trailing edge of the teeth of the first comminuting roll arranged to face away from the rotation direction of first comminuting roll, the hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

The method may comprise forming a hard region on the leading edge of the teeth of the second comminuting roll having a greater hardness than a trailing edge of the teeth of the second comminuting roll, the trailing edge being arranged to face away from the rotation direction of the second comminuting roll.

The method may comprise laser-cladding a wear resistant layer onto the leading or trailing edge of the teeth of the first or second comminuting rolls.

The method may further comprise air hardening at least one edge of the teeth of the comminuting rolls. Air hardening of the at least one edge of the teeth may be performed prior to, or after, laser-cladding the wear resistant layer. For example, manufacturing the comminuting rolls may comprise air hardening the cylindrically shaped rolls prior to laser-cladding the wear resistant layer. Air hardening may be achieved after the wear resistant layer has been deposited due to the heat input of the laser cladding process.

Manufacturing the comminuting rolls may comprise laser hardening an edge of the teeth which is not clad with a wear resistant layer. The laser hardening may comprise heating an edge of the teeth with a laser source, the heat treated tooth then being allowed to cool in air to cause air hardening of the tooth edge. Laser hardening of the non-clad edge of the teeth may be performed prior to, or after, laser-cladding the teeth with the wear resistant layer.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. **1** is a side view of a forage harvester in accordance with the invention;

FIG. **2** is a schematic view of a crop flow channel of the forage harvester of FIG. **1**;

FIG. **3** is a cross-sectional view of a crop processor according to the present invention;

FIG. **4** is a perspective view of a pair of crop comminuting rolls, of the crop processor of FIG. **3**, in an assembled state;

FIG. **5** is a plan view of the pair of crop comminuting rolls of FIG. **4**, illustrating an opening between the crop comminuting rolls;

FIG. **6** is a cross-sectional view of a plurality of teeth of a first crop comminuting roll of FIG. **3**;

FIGS. **7***a* and **7***b* are cross-sectional views of the crop comminuting rolls of FIG. **4**, illustrating wear on a plurality of teeth of the crop comminuting rolls during use of the crop processor;

FIG. **8** is a schematic view of a method of depositing a wear resistant layer on the plurality of teeth of a crop comminuting roll;

FIG. **9** is a flow chart showing the method steps of a method suitable, according to the present invention, of manufacturing a crop processor; and

FIGS. **10** and **11** are perspective views of a plurality of teeth of a comminuting roll, illustrating the profile of the teeth before and after a grinding process, respectively.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and which illustrate specific embodiments of the invention. These embodiments are described in sufficient detail to enable those of ordinary skill in the art to make and use them. Aspects of the present invention will now be described with reference to FIGS. **1** to **9**.

FIG. **1** shows a harvesting vehicle **100** in the form of a forage harvester **100**. The forage harvester **100** is configured to harvest crops C such as maize and grass that can, for example, be used in the production of animal feed.

To this end, a front end **102** of the forage harvester **100** comprises a header **104**, a crop processor **10** and a spout **106**. The header **104** is configured to cut and gather crop C from a field as the forage harvester **100** moves forward. A set of feed rolls **108** is arranged to draw the cut crop into a crop flow channel **110**, as shown in FIG. **2**. In the crop flow channel **110**, the crop is processed and then guided into the spout **106**. The spout **106** discharges the crop material out of the forage harvester **10** into a trailer (not shown) adjacent to or behind the forage harvester **100**.

To harvest maize, for example, the crop flow channel **110** comprises a chopper **112**, a crop processor **10** and a blower **114**, the crop processor **10** being arranged between the chopper **112** and the accelerator **114**. The chopper **112** chops the crop drawn into the crop flow channel **110** into small pieces. The crop processor **10** then grinds and crushes the chopped crops, including the maize kernels, so as to make accessible all available nutrients therefrom. To this end, the crop processor **10** is made up of two toothed rolls with a very small gap therebetween. The accelerator **114** then accelerates (most of) the processed crop into the spout **106** for discharging. The feed rolls **108**, the chopper **112**, the crop processor **10**, the accelerator **114** and the spout **106** are shown in FIG. **2**.

A crop processor **10** according to the present invention is shown in FIG. **3**. The crop processor **10** is arranged to be mounted within a forage harvester, as would commonly be known in the art. During use, the harvested crop is fed through the crop processor **10** whereupon they are cracked open before being expelled from the harvester through a spout.

The crop processor **10** comprises a housing **12** having an inlet **14** and an outlet **16** and a pair of crop comminuting rolls **18** arranged in a path (indicated by the arrows **20**) between the inlet **14** and the outlet **16**. Each comminuting roll **18** is provided with a plurality of teeth **22** arranged along a circumference of the comminuting rolls **18**. The plurality of teeth **22** extend along the length of the comminuting rolls, in an axial direction, as shown in FIG. **4** which illustrates a perspective view of the crop comminuting rolls **18** in isolation from the housing **12**. In this way, the plurality of teeth **22** are arranged to cover at least a portion of a circumferential surface of each of the comminuting rolls **18**.

The crop comminuting rolls **18** are mounted parallel to each other in the housing **12** of the crop processor **10**. In this way, the crop comminuting rolls **18** are arranged such that their respective longitudinal axes are substantially aligned with one another. The crop comminuting rolls **18** are spaced apart so as to define an opening between the rolls **18**. The opening **30** between the crop comminuting rolls **18** comprises a depth—or spacing (S), as shown in FIG. **5** which illustrates a plan view of the crop comminuting rolls **18** in isolation from the housing **12**. The opening **30** has a substantially equal depth along the length of the rolls **18**, owing to the parallel alignment of the comminuting rolls **18** within the housing **12**.

The crop comminuting rolls **18**, as applied in a crop processor **10** according to the present invention, have a diameter ranging from 200 mm to 450 mm and are provided with a number of teeth along its circumference, ranging from 90 to 300. The pair of crop comminuting rolls **18** includes a first comminuting roll **24** and a second comminuting roll **26**. The first comminuting roll **24** is arranged to rotate in a counter-clockwise direction whereas the second comminuting roll **26** is arranged to rotate in a clockwise direction (as indicated by arrows **28** in FIGS. **3**, **4**, **6**, **7***a* and **7***b*).

During operation of the crop processor **10**, a flow of harvested crops entering the crop processor **10** via the inlet **14**, is directed—or transported—by the plurality of teeth **22** and forced through the opening **30** that is provided between the outer cylindrical peripheries of the rolls **18** and further towards the outlet **16** through which it is then expelled from the crop processor **10**.

The plurality of teeth **22** on each of the comminuting rolls **24**, **26** have a substantially triangular profile, as shown in FIG. **6**. The plurality of teeth **22** are arranged with an asymmetrical profile when viewed from an axial section of the comminuting roll **24**, **26**.

The axial section is defined as a cross section obtained by slicing through the comminuting roll **24**, **26**, along a plane which intersects at a right angle to a longitudinal axis of the roll.

Each tooth has a height (H) which is measured in a substantially radial direction of the roll on which the tooth is arranged. The plurality of teeth **22** each further comprise a length (L), which is measured in an axial direction of the comminuting rolls **18**, as shown in FIG. **4**. According to the presently described arrangement, the length (L) of the plurality of teeth **22** is equal to the length of the comminuting roll **18** on which the teeth are arranged. Each tooth further comprises a width C which is measured in a substantially circumferential direction of the respective roll.

Owing to the rotation of the comminuting rolls **24**, **26**, the teeth **22** are functionally defined as comprising a leading edge **32**, **42** and a trailing edge **34**, **44**, as shown in FIGS. **6**, **7***a* and **7***b*. The leading edge **32**, **42** of each tooth is defined as the edge which faces in—or is arranged to face in—the direction of the movement of the comminuting roll **24**, **26** (as indicated by the arrows **28**). The trailing edge **34**, **44** of each tooth **22** is defined as the tooth edge which faces in a reverse direction to the rotational movement of the crop comminuting roll on which it is arranged (i.e. being arranged so as to face in the opposing direction to the corresponding leading edge **32**, **42**).

Each of the plurality of teeth **22** of the first comminuting roll **24** further comprises a substantially flat-top edge **36**. In this way, a tip region **38** of each tooth is thus not point-shaped but has a flattened outer—or peripheral—surface. Each flat-top edge **36** comprises a width (W), which is measured in the circumferential direction of the respective comminuting roll on which the tooth is formed, as shown in FIG. **6**. The teeth **22** of the second comminuting roll **26** are also configured with flat-top edges **46** having the same dimensions as the teeth of the first comminuting roll **24**, as indicated in FIG. **7***a*.

The asymmetrical profile—or shape—of the teeth **22** is such that each tooth may be described as comprising an 'aggressively sloped' side and a 'shallow sloped' side. For example, the teeth **22** of the first comminuting roll **24** each have a first side comprising a steep slope—also referred to as the aggressively sloped side—and a second side with a shallower slope—also referred to as the shallow sloped side. According to the exemplary arrangement described herein, the first communitive roll **24** is configured such that the aggressively sloped side is the leading edge **32** and the shallow sloped side is the trailing edge **34**. The second communitive roll **26** is arranged such that the aggressively sloped side of the teeth is the trailing edge **44** and the shallow sloped side is the leading edge **42**.

Owing to the asymmetric profile of the teeth, the plurality of the teeth can be defined as having an inherent directionality based on the direction in which the aggressive edge is facing. Further, the plurality of teeth **22** of the first and second comminuting rolls are arranged with the same directionality. For the case of the first comminuting roll **24**, the plurality of teeth **22** are arranged such that they are pointing in the rotation direction of the roll. By contrast, the teeth **22** of the second comminuting roll **26** are pointing in a direction which opposes the rotation direction of the second comminuting roll **26**.

During operation of the crop processor **10**, the comminuting rolls **24**, **26** are arranged in such a manner that the harvested crop which enters the crop processor **10** via the inlet **14** is engaged, initially, by the aggressively sloped side of the teeth of the first comminuting roll **24** and the shallow sloped side of the teeth of the second comminuting roll **26**. A majority of the kernel cracking is done between the aggressively sloped sides of the teeth of the first and second comminuting rolls **24**, **26** the rolls, which is caused primarily due to the relative speed differential between the rolls. As the crop passes through the opening **30**, it is further engaged by the other edges of the teeth, including the respective trailing, leading and flat-top edges.

It will be appreciated that, whilst the crop comminuting rolls **18** according to the presently described embodiment are each provided with a plurality of teeth **22** having an asymmetrical profile, the comminuting rolls **24**, **26** may be configured, alternatively, with symmetrically shaped teeth having leading, trailing and flat-topped edges as described above.

During use, the communitive rolls **24**, **26** are configured to rotate at different speeds. According to the exemplary arrangement described herein, the first comminuting roll **24** is arranged to rotate at a greater speed than the second comminuting roll **26**, as indicated by the double arrows **28** shown in FIGS. **7***a* and **7***b*. Hence, during operation of the crop processor **10**, the crop kernels which pass through the opening **30** between the rolls are crushed between the leading edge **32** of the teeth of the first (faster rotating) comminuting roll **24** and the trailing edge **44** of the second (slower rotating) comminuting roll **26**. The speed differential between the first and second comminuting rolls **24**, **26** is at least 10%, and no more than 50%, in order to affect the crop kernel cracking.

During use, an irregular flow of harvested crop leads to the irregular wear of the length of each comminuting roll. In particular, a greater flow of harvested crop material passing through the center of the rolls than at the sides causes more wear in the center than at the sides, which results in an unequal opening between the rolls. As a result, the effectiveness of the kernel cracking process of the harvested crop deteriorates over time. The comminuting rolls must then be replaced at more regular intervals due to the irregular wearing of the comminuting rolls, thereby increasing the maintenance costs of the forage harvester. It will be appreciated, that the above described wear process can also occur when a symmetrical tooth profile is applied to the comminuting rolls. In addition, the cracking process itself also results in wear of the teeth and thus results in the occurrence of an irregularly enlarged opening between the rolls.

To enable the teeth to withstand wear caused by kernel cracking, it is known to configure the teeth of the comminuting rolls such that the leading and trailing edges of the teeth exhibit an elevated uniform hardness. For example, the comminuting rolls may be manufactured from a material which has, or is configured to have, a uniform surface hardness. First, the comminuting rolls are subjected to an induction hardening treatment which involves inducing an alternating magnetic field in the surface of the comminuting rolls to cause localised heating of the peripheral surface to a temperature which is above the transformation range of the constituent alloy. The localised heating leads to hardening of the surface of the comminuting rolls, whilst its core remains substantially unaffected by the treatment. The resulting heat treatment has an equal hardening effect on both the leading and trailing edges of the teeth.

To further increase the wear resistance of the comminuting rolls, the surface of the teeth (i.e. both the leading and trailing edges) can also be coated with a thin hard chrome layer, following the induction hardening treatment. Such chrome plating techniques typically require the use of hexavalent chromium which is a toxic substance, the use of which is increasingly restricted by government legislation.

A drawback of induction hardening process is that it tends to concentrate energy in the tip region of the teeth, which can cause localised melting of the tip region. The hardening process also causes deformation in the roll due to metallurgical transitions in the material.

Furthermore, the chrome electro-plating process causes indiscriminate hardening of both the leading and trailing edges of the teeth, which contributes to the irregular wearing of the comminuting rolls during operation of the crop processor, as described above. In particular, the uniform hardening causes a gradual, but irreversible blunting of the teeth of the comminuting rolls during operation of the crop processor.

In accordance with the present invention, an alternative arrangement of the first and second comminuting rolls **24**, **26** is proposed which is less susceptible to wear. This is realised by configuring the second (slower moving) comminuting roll **26** such that the leading edges **42** of the plurality of teeth are provided with a hard region **50**, which has a greater hardness than the leading edge **32** of the teeth of the first (faster moving) comminuting roll **24**.

The advantageous benefits of the hard region **50** can be appreciated by considering the operation of the crop processor **10**, as illustrated in FIGS. **7***a* and **7***b*. During operation of the crop processor **10**, crop material is directed towards the comminuting rolls **24**, **26**, from below. The rotation of the comminuting rolls causes the crop material to be engaged by the leading edges **32**, **42** of each comminuting roll **24**, **26**. The motion of the teeth's leading edges **32**, **42** directs the crop material in a substantially upward direction towards the opening **30**. As the crop material approaches the narrowest point of the opening **30**, the relative speed differential between the comminuting rolls **24**, **26** causes the opposing sets of teeth to grip the crop material, effectively tearing it apart.

The above described grinding process leads to the leading edges **32** of the teeth of the first comminuting roll **24** to be worn at an increased rate, relative to the leading edge **42** of the teeth of the second comminuting roll **26**. This is due to the increased hardness of the hard region **50** on the second comminuting roll **26** and, in particular, its ability to withstand the abrasive forces associated with the kernel cracking process. The preferential wearing of the leading edge **32** leads to a sharpening of the teeth of the first comminuting roll **24**, as indicated by the convex shaping of the teeth in FIG. **7***b*. Advantageously, this sharpening effect helps to prolong the life of the comminuting roll **24**, which thereby reduces the maintenance costs associated with the crop processor **10**.

A further hard region **48** is provided on the trailing edge **34** of the first comminuting roll **24**. This hard region **48** is arranged to exhibit a greater hardness than the leading edge **32** of the teeth of the first comminuting roll **24**. The hard region **48** of the teeth **22** of the first comminuting roll **24** further contributes to the preferential wearing of the leading **32** and trailing edges **44** of the teeth of the first and second comminuting rolls **24**, **26**, respectively. Similarly to the first comminuting roll **24**, the trailing edge **44** of the second comminuting roll **26** is caused to wear away quicker than the hard region **50** of the leading edge **42**, which will result in a sharpening of the teeth **22** of the second comminuting roll **26** during operation of the crop processor **10**. Accordingly, the hard regions **48**, **50** are arranged to exhibit a greater hardness than the trailing edge **44** of the teeth of the second comminuting roll **26**.

The flat-top edges **36**, **46** of the teeth are also provided with a hard region **52** having a greater hardness than each of the leading edge **32** of the teeth of the first comminuting roll **24** and the trailing edge **44** of the teeth of the second comminuting roll **26**. The hard region **52** defines a continuation of hard regions **48**, **50** of the leading **42** and trailing **34** edges of the teeth of the first and second comminuting rolls **24**, **26**, respectively, as illustrated in FIGS. **6** and **7***a*.

Each of the hard regions **48**, **50**, **52** is arranged to cover at least a portion of the underlying surface of the edge onto which they are provided. For example, the hard region **48** is arranged to extend over a portion (P) of the trailing edge **34** of the teeth of the comminuting roll **24**, as shown in FIG. **6**. The proportion of the teeth surface which is covered by the hard region is determined according to the wear requirements of the roll, as will appreciated by the person having ordinary skill in the art.

The laser-cladding process enables the selective deposition of the wear resistant layer onto just one of the leading and trailing edges of the teeth, which thereby enables the sharpening effect as described above. The laser cladding process will now be described with particular reference to FIG. **8**, which illustrates the first comminuting roll **24** undergoing the laser-cladding treatment in isolation from crop processor **10**.

A laser cladding system is used to deposit the wear resistant material on to the edge of the teeth which is to be hardened. A laser source of the cladding system is configured to direct a laser beam on to the surface of the teeth creating a melt pool. A nozzle **52** of the cladding system provides a stream of powdered precursor, which interacts with the melt pool to form a metal-to-metal bond between the wear resistant material and the underlying surface of the teeth. To achieve this, the nozzle **52** is linearly translated along the length of the comminuting roll **24**, in a direction which is substantially parallel with its rotation axis, whilst continuously depositing a narrow track of molten material along the trailing edge **34** of a single tooth **22** of the first comminuting roll **24** (i.e. the less aggressive tooth edge).

Once the nozzle **52** has reached one end of the comminuting roll **24**, the comminuting roll **24** is rotated incrementally in order to align the nozzle **52** with the trailing edge **34** of the neighbouring tooth of the roll **24**. The nozzle **52** is then translated in the opposite direction along the length of the roll **24** depositing the molten wear resistant layer as it goes. This process is then continued until each of the trailing edges **34** of the teeth **22** of the first comminuting roll **24** have been clad with the wear resistant material. The laser-cladding process is then applied to the second comminuting roll **26**.

According to an alternative cladding method, the comminuting roll is installed on a lathe-type machine and rotated during the deposition of the wear resistant material. In particular, the roll is rotated while the nozzle **52** is configured to move from one end of the roll to the other end, in a longitudinal direction. The wear resistant layer is therefore applied in a densely packed spiral pattern along the length of the roll. The rotational and lateral speeds of the roll and the nozzle are controlled, respectively, so as to produce a continuous wear resistant layer along the length of each tooth.

The dispensing nozzle **52** is configured to deposit a narrow track of molten wear resistant material such that it only covers a portion (P) of the trailing edge **34**, as shown in FIG. **6**. Translating the nozzle **52** along the length of the roll **24** allows the melt pool to solidify and thus produces a continuous layer of solid material.

Laser cladding of the hard region **48** improves the wear resistance of the coated teeth due to high tungsten carbide composition of the wear resistant material. The resulting wear resistant layer has a composition of tungsten carbide.

The wear resistant layer is fused at high temperature onto the teeth in order to form a strong bond between it and the underlying roll surface. This is in contrast to the known chrome facing techniques which, due to the electrolytic process, means that there is no real metallic binding between the base material and the hard chrome layer. Accordingly, the wear resistant material of the hard regions **48**, **50**, **52** is able to withstand impacts from hard stones without risking the layer being chipped off from the teeth, as is common with an electroplated chrome layer.

Laser cladding enables the deposition of wear resistant material between individual features of the finely serrated peripheral surface of the rolls (i.e. between the individual teeth). The heat input of the laser cladding process is small and local to the surface of the rolls so that the underlying material does not melt away, which thereby minimises the deformation of the rolls. Thus, the above described laser cladding process is suitable for comminuting rolls **18** formed of induction hardened alloy compositions.

The comminuting rolls **24**, **26** are formed of a material which is configured to provide a hardened surface when subjected to an air hardening process. The air hardening process involves allowing a cast metal alloy to cool over a relatively long cooling period. This is typically achieved by allowing the metal alloy roll to be cooled in air. The air hardening approach is distinct from alternative methods of forming metal alloy components which involve quenching in a fluid, such as water. The speed of the cooling due to air hardening causes slow dissipation of thermal energy from a small melted zone at the surface of the roll into the rest of the material, which results in the formation of a hard surface layer of each comminuting roll **24**, **26**. The air hardening process advantageously alleviates the need to use additional surface treatments such as inductive hardening which can cause localised deformation of the teeth, particularly in the tip region **38**.

Once the teeth have been machined into the rolls, they are subjected to a hardening process. According to a first hardening process, the cylindrically shaped rolls are heated up to a suitable hardening temperature and then allowed to cool in air. In particular, the first and second comminuting rolls **24**, **26**, are air hardened to form a surface with a hardness which is sufficient to withstand the grinding of crop kernels during the operation of the crop processor **10**. The air hardening of the rolls is performed prior to depositing of the wear resistant material. In order to facilitate the air hardening process, the teeth are manufactured from steel, or any suitable material which has sufficient hardenability to enable air hardening of the teeth surfaces.

Alternatively, air hardening of the teeth may be implemented due to the heat input from the laser cladding process. In particular, the laser source of the cladding system is configured to form a melt pool on the surface of the teeth during the laser cladding process. The melt pool defines a heat treated region of the teeth which undergoes air hardening as it cools. Air hardening is thereby achieved after the deposition of the wear resistant layer.

According to an alternative hardening process, the teeth may be subjected to a laser hardening process. In this case, the heat used to perform the hardening process is provided by a high powered laser, which is configured to direct a beam of laser light on to an edge of the teeth. Once the laser treated edge has been heated, it is then allowed to cool in air. In this way, the laser treated edge is air hardened.

The laser hardening process is used to harden the un-clad surface of each tooth, i.e. the edge of the tooth which is not clad with wear resistant material. The laser hardening process creates a heated zone under the laser treated edge of the teeth. The heated zone exhibits increased hardness, relative to the remainder of the teeth. Advantageously, the laser hardening process enables individual edges of the teeth to be targeted, without affecting other regions of the teeth. The laser hardening process may be performed either before or after the cladding of the wear resistant layer. In order to facilitate the laser hardening, the teeth should be manufactured from steel, or any suitable material which has sufficient hardenability to enable air hardening of the teeth surfaces.

The air-hardened teeth surface leads to the preferential wearing of those teeth edges which are not subjected to the laser-cladding treatment, thereby leading to the sharpening effect as described above. Advantageously, each of the steel compositions enable the forming of an air hardened surface region of the teeth which exhibits a hardness rating within the prescribed hardness range. Advantageously, it is the selective deposition of the hard regions **48**, **50** which, when combined with the underlying air-hardened alloy of the comminuting rolls **24**, **26**, enables the sharpening effect of the un-treated edges (i.e. the teeth edges which are not provided with a laser-clad hard region) of the teeth **22**, as shown in FIG. **7***b*.

The laser hardening treatment may be selectively applied to the teeth **22** in order to increase the wear resistance of the non-cladded edge of the teeth **22**. The wear resistance of the laser treated edge is still less than that of the wear resistance layer which is formed on the teeth **22** of the opposing comminuting roll. Therefore, the self-sharpening effect is retained due to the relative difference in wear resistance—or hardness—between the cladded and non-cladded edges of the teeth **22** arranged on the opposing comminuting rolls **24**, **26**.

Manufacturing a crop processor **10** in accordance with the present invention requires the manufacture of crop comminuting rolls **18**, as described above. Crop comminuting rolls are made from metal, often a ferrous metal. Starting from a cylindrically shaped roll, various processes are performed such as machining the teeth and hardening the machined roll, in order to arrive at a roll that can be applied in a crop processor **10**. A method **80**, **180** of manufacturing a crop processor **10**, according to an aspect of the present invention, will now be described with reference to FIGS. **8** and **9**, in particular.

The manufacturing method **80** commences with manufacturing a first and a second comminuting roll **24**, **26**. In a first method step **82**, **182**, a pair of substantially cylindrical shaped rolls is provided. As described above, the comminuting rolls **24**, **26** are made of a material which can be configured to provide a hard surface when subjected to air hardening, so as to enable the sharpening effect of the un-treated edges of the teeth **22**. To enable the self-sharpening effect, the un-treated edge of the teeth **22** must therefore be softer than the treated edge. The plurality of teeth may be manufactured from at least one of steel alloys.

In a second method step **84**, **184**, a plurality of teeth **22** are formed by machining the plurality of teeth into the substantially cylindrically shaped rolls, thereby maintaining part of an outer surface of the rolls unaffected. The resulting teeth **22** each comprise a leading edge **32**, **42** arranged, during use, to face in a rotation direction of the comminuting roll **24**, **26**, and a trailing edge **34**, **44** which faces away from the rotation direction of the crop comminuting roll **24**, **26**, as described above. The rolls are machined such that they retain a flat surface on the outer diameter of the rolls. The flat edge defines the flat top edge **36**, **46** of the teeth **22** of the comminuting rolls **24**, **26**. Alternatively, the rolls may be machined such that they do not retain a flat top surface on the outer diameter of the rolls, according to a variant of the second method step **184**. Accordingly, the teeth which are formed using this method do not yet comprise a flat top edge, which may be provided in a later manufacturing step.

In a third method step **86**, **186**, a hardened surface **48** is formed on the trailing edge **34** of the teeth of the first comminuting roll **24**. In a fourth step **88**, **188**, a hardened surface **50** is formed on the leading edge **42** of the teeth **22** of the second comminuting roll **26**. It will be appreciated that the method steps **86**, **186** and **88**, **188** may be carried out in any order. Forming each of the hardened surfaces **48**, **50** comprises laser-cladding a wear resistant layer onto the trailing **34** and leading **42** edges of the teeth **22** of the first and second comminuting rolls **24**, **26**, respectively. Prior to the forming the wear resistant layer, the comminuting rolls may be subjected to an air hardening treatment. Alternatively, air hardening may be achieved after deposition of the wear resistant layer due to the heat input from the laser cladding process. Optionally, the teeth may be subjected to a separate laser hardening treatment, as described above.

According to the variant of the second method step **182** as described above, the rolls are machined with a plurality of teeth without forming an outer flat surface at the roll diameter. The rolls that have been machined in this way are now subjected to an additional method step **190**, in which a substantially flat-top edge is machined—or ground—onto the plurality of teeth. The flat-top edge grinding process is arranged to follow the deposition of the hard region **48**, **50**. The effect of the grinding process is illustrated in FIGS. **10** and **11**, which show the teeth **22** of a comminuting roll before and after the grinding has taken place, respectively.

The grinding process ensures that the finished rolls **24**, **26** are cylindrical after the laser cladding. The grinding process also produces a sharp edge at the hard region **48**, **50** towards the tip region of the teeth **22**. It also defines the flat-top edge **36**, **46** at the outer diameter of the comminuting roll **24**, **26**. The effect of the grinding process reduces the variation in the shape of the deposited hard region **48**, **50**, which occurs due to the surface tension of the molten phase during deposition. The surface tension can result in a rounded outer edge in the tip region **38** of the teeth **22**, as illustrated in FIG. **10**. The resulting variation in the hard region **48**, **50** can create an uneven reduction in the diameter of the rolls. This rounding can result in an inconsistent opening **30** between the comminuting rolls **24**, **26**.

Advantageously, the grinding process removes the rounding of the hard region **48**, **50**, thereby producing a sharp edge at the flat-top edge **36**, **46** of the teeth **22**, as shown in FIG. **11**. The grinding process also helps to reverse any deterioration in the cylindricity of the comminuting rolls **24**, **26** which may be caused due to slight variations in the layer thickness of the hard region **48**, **50**. The flat-top edges also help to maintain the spacing (S) between the comminuting rolls **24**, **26** when they are installed within the crop processor, as shown in FIG. **5**. An accurate and consistent cylindricity of the comminuting rolls **24**, **26** is needed in order to achieve a correct and narrow alignment of the roll **24**, **26**. In particular, the combined laser-cladding and grinding processes enable the opening **30** to be configured, over the entire length of the rolls, within a clearance of 1 mm.

In a final method step **92**, **192**, the comminuting rolls **24**, **26** are assembled into the crop processor housing **12**. The comminuting rolls **24**, **26** are arranged in parallel so as to define the opening **30** between the comminuting rolls **24**, **26**. The comminuting rolls **24**, **26** are configured to rotate, during use, in opposing directions to transport a flow of harvested crop kernels, received from the inlet **14**, through the opening **30** towards the outlet **16**. The first comminuting roll **24** is configured to rotate at a greater speed than the second comminuting roll **26**.

The invention claimed is:

1. A crop processor for cracking kernels in a forage harvester, the crop processor comprising: a housing having an inlet and an outlet; and a first comminuting roll and a second comminuting roll, both mounted inside the housing, the first comminuting roll and the second comminuting roll being arranged in parallel to define an opening between the first comminuting roll and the second comminuting roll, wherein the first comminuting roll and the second comminuting roll are configured to rotate, during use, in opposing rotation directions to transport a flow of harvested crop, received from the inlet, through the opening towards the outlet, wherein the first comminuting roll is configured to rotate at a greater speed than the second comminuting roll,
- wherein the first comminuting roll and the second comminuting roll each comprise a plurality of teeth arranged on a circumferential surface thereof, each of the plurality of teeth comprising a leading edge which faces in the rotation direction of the comminuting roll on which the plurality of teeth are arranged,
- wherein the leading edge of the teeth of the second comminuting roll comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll, and
- wherein the plurality of teeth of the first comminuting roll comprise a substantially flat-top edge; wherein the substantially flat-top edge comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

2. The crop processor according to claim **1**, wherein a trailing edge of the teeth of the first comminuting roll comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

3. The crop processor according to claim **1**, wherein the hard region of the leading edge of the teeth of the second comminuting roll has a greater hardness than a trailing edge of the teeth of the second comminuting roll.

4. The crop processor according to claim **1**, wherein the plurality of teeth of the second comminuting roll comprise a substantially flat-top edge; wherein the substantially flat-top edge comprises a hard region having a greater hardness than the trailing edge of the teeth of the second comminuting roll.

5. The crop processor according to claim **1**, wherein the hard region comprises a wear resistant layer having been deposited by laser-cladding.

6. The crop processor according to claim **1**, wherein the teeth comprise an air hardened surface region.

7. The crop processor according to claim **1**, wherein at least one edge of the teeth comprise a laser hardened surface region.

8. The crop processor according to claim **1**, wherein the plurality of teeth have an asymmetrical profile in an axial section of the comminuting roll on which the plurality of teeth are arranged.

9. A forage harvester comprising a crop processor according to claim **1**.

10. A method of manufacturing a crop processor for cracking kernels in a forage harvester, the method comprising:
- manufacturing a first comminuting roll and a second comminuting roll; and
- assembling the comminuting rolls into a housing having an inlet and an outlet, the first comminuting roll and the second comminuting roll being arranged in parallel to define an opening between the first comminuting roll and the second comminuting roll,
- wherein the first comminuting roll and the second comminuting roll are configured to rotate, during use, in opposing directions to transport a flow of harvested crop, received from the inlet, through the opening towards the outlet,
- wherein the first comminuting roll is configured to rotate at a greater speed than the second comminuting roll, and wherein manufacturing the first comminuting roll and the second comminuting roll comprises:
- providing a pair of substantially cylindrical shaped rolls;
- machining a plurality of teeth in the substantially cylindrical shaped rolls, each of the plurality of teeth comprising a leading edge arranged, during use, to face in a rotation direction of the crop comminuting roll in which the plurality of teeth are machined;
- forming a hard region on the leading edge of the teeth of the second comminuting roll, the hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll; and
- wherein the plurality of teeth of the first comminuting roll comprise a substantially flat-top edge;
- wherein the substantially flat-top edge comprises a hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

11. The method according to claim **10**, wherein the method further comprises forming a hard region on a trailing edge of the teeth of the first comminuting roll arranged to face away from the rotation direction of first comminuting roll, the hard region having a greater hardness than the leading edge of the teeth of the first comminuting roll.

12. The method according to claim **10**, wherein forming the hard region comprises forming the hard region on the leading edge of the teeth of the second comminuting roll to have a greater hardness than a trailing edge of the teeth of the second comminuting roll, the trailing edge being arranged to face away from the rotation direction of the second comminuting roll.

13. The method according to claim **10**, wherein forming the hard region comprises laser-cladding a wear resistant layer onto an edge of the teeth of at least one of the first comminuting roll and the second comminuting roll.

14. The method according to claim **13**, wherein manufacturing the first comminuting roll and the second comminuting roll further comprises air hardening at least one edge of the teeth.

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